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Approaching Humans For Help: A Study of Human-Robot Proxemics

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Abstract

In order for a robot to be effective when interacting with a person, it is important for the robot to chose the correct person. Consider an example where a robot is trying to perform a task but it isn't capable of doing a subtask, like going up a flight of stairs. In this case, the robot would need to ask a person for help with the elevator, in a socially appropriate way. We have conducted an experiment to determine who would be the best candidate to approach in a situation like this. Should the robot choose to approach someone who is very close, with the risk that the person may have already committed to passing? Or someone who is further away, which could result in the person not noticing the robot at all. Our hypothesis is there is some optimal distance that is not too close nor too far away. We tried approaching from different distances to see which distance led to the most successful interactions. The result provide guidance for developers of autonomous robots who need a robot to approach someone for help.

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1 Introduction

Robots are tools designed to help people. As with most technology, they are built to make our lives easier. As time progresses robots are becoming more and more integrated in society. A perfect example of a robot in today's society is the Roomba. It does one task of vacuuming autonomously. It makes use of simple bumper sensor technology so that it is inexpensive for the everyday consumer. Robots of the near future are going to be similar to the Roomba in that they won't be do-all robots. They will have specific tasks that they are able to carry out. The Terminator, for example, could do everything, but creating the Terminator now would be an extraordinary accomplishment that would be very expensive.

Since robots can't do everything, and ones that can do more than others are expensive, we have to make use of the resources we have available to us. Therefore, we have to use inexpensive parts to build the robot, and make use of the robot's environment in a beneficial way. Let's say we want to have a mobile robot. Historically, putting legs on a robot causes instability, and if you want to assure stability it would be expensive. Thus, the simpler and less expensive approach is to just put wheels on the base of a robot. However, this makes it so the robot won't be able to go upstairs. A solution to this is make use of the robot's environment and use the elevator. But, the robot may or may not have arms, and if it does, it might not have the ability to push the buttons on the elevator. For example, the Shadow Robot Company has a robot arm that would be able to do this task, but it costs roughly $14,000 for just one hand [2].

A more practical solution to the elevator problem, would be to ask a person for help. Before we look into how a robot would accomplish the task of asking someone for help, we have to consider social norms. Since it appears that the future will have robots in it, they need to integrate into society well. Meaning that they have to follow social norms, so that they are still a tool rather than a burden. If you have a robot that gets you coffee, the robot can't just charge to the front of the line and demand coffee, it needs to appropriately wait in line to order the coffee.

Similarly, if a robot needs help, we need to find an appropriate way to approach for help. A few solutions intuitively can be eliminated. For example, we aren't going to have a robot quickly approach someone from behind. It would be very threatening if a person ran towards someone else when their back was turned, just to ask for help with the elevator. We also don't want to ask someone for help who appears to be in a hurry, as they are less likely to be willing to help since they are already engaged in something else. Thus, it seems that finding an appropriate way to approach someone depends on who it is we are approaching. Therefore, finding who the appropriate person to approach is important. When we are choosing a potential candidate to approach and engage, we have to find the person who will be most willing to help. However, we don't have a lot of information on the people who we are choosing between, making the problem challenging.

On the other hand, some information is easy to determine based on data from on-board senors. Let's consider one variable that we can determine about the person: their relative distance to the robot in the environment that they are both in. Choosing a person who is very far away from the robot has pros and cons. It will give the person plenty of time to see and expect interaction with the robot, but if they are very far away maybe the robot won't get their attention in the first place. Similarly, if you chose a person who is very close to the robot, they may have already decided to pass the robot, and therefore won't be willing to help. Also, if someone is that close, it may be too intimate of a space to ask them for help. In this research, we attempt to determine what an appropriate distance at which a robot can approach someone for help. Once we find what the appropriate distance is, we have a better understanding of who to approach. This will not give us the exact answer, but it narrows down the pool of potential candidates to people who will be more likely to help the robot upon approach.

2 Related Work

Satake, et al., [9] has done work on *approaching people* and shown that it is harder than it seems. Approaching someone is not as simple as sending the robot in the direction of the person. Satake, et al., did work with having a robot lead people around a mall. In order for a robot to help lead people, the robot needs to first get a persons attention. It tries to do so by approaching them. An approach is a non-verbal way of communicating, the intent in this situation is for the robot to get the person's attention so it can help them navigate the mall. Again, having a robot approach a person is a difficult task, and Satake, et al., found that if the robot plans the path of the person, the robot has more success at approaching. A successful approach leads to getting the persons attention, which can lead to interacting with the robot. As shown in Figure 1 the robot must be able to see the person, determine their speed and project their path so that it can be in

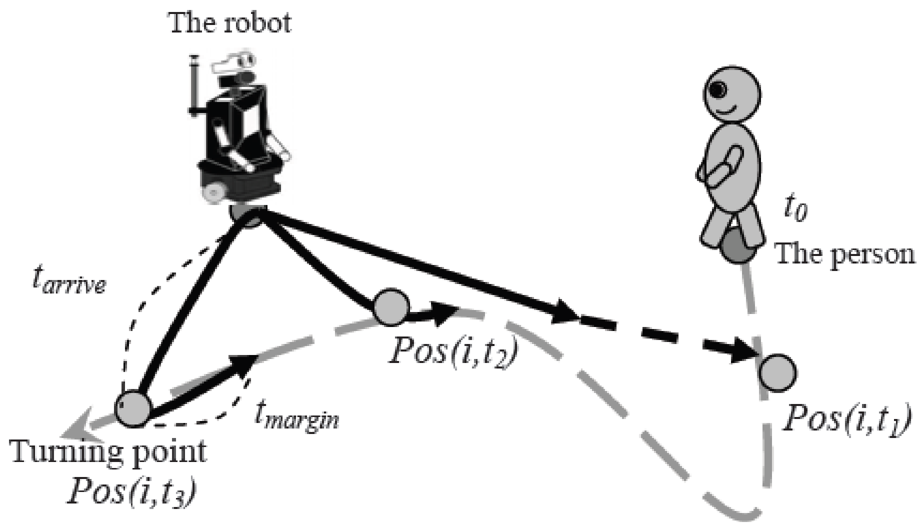

Figure 1: Diagram showing how to predict the path of a person [9].

the ideal position when trying to initiate interaction. This research however, made use of very expensive environmental lasers. These lasers were placed in the area where the robot was trying to approach people to assist the robot with data on the people it could approach. Our research wanted to have a robot that could successfully approach people regardless of the environment. Satake, et al., showed that having an autonomous robot approach someone is a difficult problem in itself, but if the robot is in an ideal position at the end of the approach it will lead to a more successful interaction.

Manuela Veloso [7] has done work on having a social robot *ask for help*. She has developed a robot which is able to guide visitors of the university through their department and bring them to specific people's offices. However, like most robot, it has limits. In this specific case, their robot had issues when navigating through glass hallways. On the other hand, the robot could easily follow a person, regardless of the environment. Thus, when the robot approached a glass hallway, it would ask the person it was navigating if it could follow them through the hallway. Veloso coined the term symbiotic autonomy to describe this situation where in order for a robot to help a person, the person also needs to help the robot when the robot has limitations. This research reinforced the fact that robots are not perfect machines and in order for them to be successful in society they need to be able to get help when they need it.

Additionally, an important note is the robot needs to go about getting help in an appropriate way for it to be successfully integrated in society. As discussed by Fong, et al., [10] an important distinction between a social robot and a conventional robot, is the way people perceive the robot. In order for our robot to be perceived as social, it needs to have human social characteristics, which include having a distinct personality and behaving in a way that is similar to a person. The way we try to give our robot personality is described in Section 3.

Edward T. Hall [6] has done work dealing with *proxemics*. Proxemics is a form of non-verbal communication. It deals with how humans interact using distances. In Figure 2, we see different reaction bubbles: intimate space (0-1.5ft), personal space (1.5-4ft), social space (4-12ft), and public space (12-25ft). What these different distances represent are the levels of comfort people associate with the distance between other people. For example, people do not like strangers in their intimate space, the intimate space is for showing affection between close people. On the other hand, the public space is for something like public speaking. Our research wants to look into is how well these different distances translate to *human-robot* interactions, rather than human-human. The hypothesis is that they will translate well, and people will be more comfortable with a robot they presumably are not familiar with approaching from a public space rather than an intimate space or personal space. This led us to our hypothesis that an appropriate distance for a robot to start approaching someone would be from some distance in the public space, 20 feet.

3 Building a Social Robot

Prior to finding this approach distance, we need to first build a robot. We named our robot SARAH, Socially Appropriate Robot that Approaches for Help. We chose the base of SARAH to be the Pioneer 3DX as pictured in Figure 3. The Pioneer is a small robot, ten inches tall, with great mobility, and a flat top. It is important for SARAH to be very mobile as she needs to be able to approach people. Additionally, the Pioneer has superior mobility on all surfaces to the other robots that we had at our disposal. The Pioneer also has a LIDAR laser attached to the top that will be used when we convert the robot from teleoperated to autonomous, which will be discussed further in Future Works.

The Pioneer having a flat top was also an important feature because it allowed for more adjust-ability

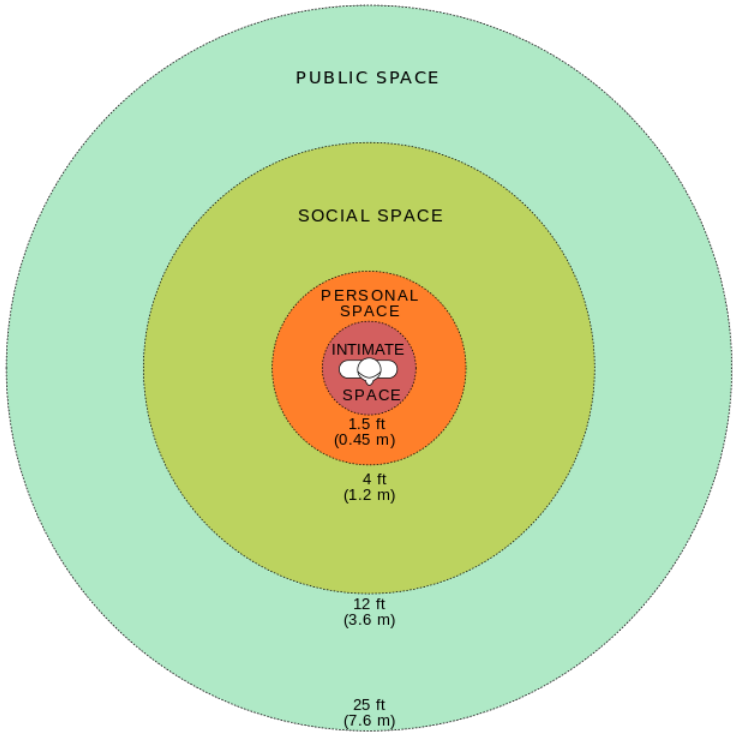

Figure 2: Hall's proxemics diagram, from wikipedia.com.

Figure 3: Pioneer 3DX[1]

Figure 4: Pioneer 3DX with stand attached

when building a stand. The stand makes the robot much taller, and as a result it will be closer to human height. The height plays a role because we want the robot to seem as if it is it's own independent social agent. Meaning, we want people to think when they see SARAH that she is acting on her own accord. If just the Pioneer base was driving around, it would seem more like a remote controlled robot. Thus, as seen in Figure 4 we built a four foot tall stand and attached it to the top of the Pioneer. We believe this will make people see her as more of an independent social agent, rather than a remote controlled car. Additionally, we needed SARAH to be tall so that when we add a face, it can be at people's head level.

The stand was constructed in a way that allowed for us to adjust the position of the uprights. Figure Figure 4 shows two bars attached to the top of the Pioneer and the uprights attached to these bars. This adjust-ability proved to be very useful because we originally had the uprights at the front of the robot, like in Figure 4, which caused instability when driving over rough terrain. Therefore, we moved the uprights so that they attached to the bars in the middle of the robot to reduce the wobble from it being top heavy.

A face gives SARAH more personality and life, which is something we want so she can appear to be more social. So, we built a mount that would hold a screen and attach to the top of the stand. The screen displays a face, as seen in Figure 5. The face has on it lively eyes, eye brows, eye lashes, and a mouth. By

Figure 5: Pioneer 3DX with stand and screen attached, displaying robot face

giving the robot characteristics of a person, but not looking exactly like a person, people will be able to anthropomorphize the robot easier [5].

SARAH makes use of ROS [3], the Robot Operating System, to function. ROS is further explained in Appendix A.

4 Methods

The purpose of this experiment is to determine the most successful distance to start approaching someone for help. This will help us answer the question, who should we approach for help?

4.1 Experiment Design

We designed a semi-controlled in the wild experiment. This was a result of the trade-offs between two design tensions: lab setting versus in the wild, and an autonomous robot versus human controlled. We chose to do a completely in the wild experiment because we wanted to elicit a natural human reaction to seeing the robot. As discussed in Cass, et al.,[4] an experiment in the lab would be idealistic and could potentially produce results that could not be replicated. An experiment in the lab would result in a threat to the external validity. Since we are looking for a natural reaction, it would be difficult to set up a experiment in the lab where the participants would be completely unaware of the experiment happening. Thus, we chose to do the experiment in the wild. This solves our issue of getting a natural reaction, but it brings in the typical issues experienced with a experiment done in the wild.

The main concerns for an in the wild experiment are we have no control over the participants and we have little control over the environment. We do not know if the people we try to approach have any experience with robots which could have a major impact on whether or not they would be willing to interact, and we have no way of asking all of the potential candidates why they did or did not chose to interact with the robot. Also, there could be a variety of different activities happening in the environment which could distract people from the experiment being run. The control that we do have over the environment is where specifically we are running the experiment. We chose to run the experiment at Union College's Reamer Campus Center. This building is a central hub for Union College. It contains two different eateries, a bookstore, the mail room and offices. Thus, there is a steady flow of traffic in and out of the building, consisting of Union College students, faculty, staff and visitors of the college.

The degree of autonomy in the control of the robot presents similar tensions to in the wild vs lab. If the robot is fully autonomous, the persons reaction will be the real reaction of seeing an autonomous robot in the wild. Additionally, having a fully autonomous robot makes it so the way the robot behaves is consistent, it depends on the sensory input rather than a person controlling the robot. However, designing a fully autonomous robot is a difficult task. It would require us to know exactly how the robot should approach, but we do not know this for sure. In fact, we are doing these experiments so we can learn more about how the robot should approach. Thus, it is much simpler to have someone controlling the robot and making it behave the way we want to. This way we do not need to reprogram every time we want to make an adjustment on the approach. Thus, we chose to make use of a Wizard-of-Oz (WoZ) setup. WoZ is further described in Appendix B.

The part of the experiment we need full control over is the distance we start approaching from. Thus, in the experiment we are placing SARAH a variable distance away from the entrance of the building. When a person enters the building, the robot will start to approach. Therefore, the distance from the robot to the entrance will act as a proxy for the initial approach distance from the robot to the person. This is a reasonable proxy because when the person enters, the robot approaches, and thus the initial approach distance is the same as the distance from entrance to robot. We are trying to determine what the most successful initial approach distance is. The distance from the robot to the entrance will be our independent variable in this experiment and the dependent variable will be the number of successful approaches. What we consider a successful approach will be discussed in Section 4.3.

4.2 The Approach

Figure 6 shows SARAH set up for an approach at a distance of twenty feet. When a person opens the door shown and starts to walk into the building, SARAH will begin her approach. She will follow a path that will put her in what we consider the optimal position for an interaction. Meaning, we want her to be directly in front of the person we are trying to interact with, when the approach is finished. Thus, she will follow a path that will position her directly in front of the person she is approaching. This way, when she stops moving she will hopefully be in the best position for an interaction. She stops approaching when either the person has fully passed by her, or the person has stopped walking. If the person has fully passed her then we know they are unwilling to help, and therefore it was an unsuccessful interaction. If the person we are approaching has stopped walking, then we are considering this to mean they are showing interest in the robot and may potentially interact with it. However, if the person stops walking immediately when they enter and the robot is still out of arms reach of the person, SARAH will continue to approach until she is within arms reach. We chose to approach until arms reach because the person needs to touch SARAH to interact with her.

Based on Hall's [6] reaction bubbles and the dimensions of the building, we chose to do approaches from 5, 10, 20 and 40 feet. These distances aligned well with landmarks in the building, making it easier to set up for each approach. By aligning SARAH with the landmark at the beginning of each approach, we were assuring that we are approaching from exactly the same distance each time. These distances also relate to Hall's work because we have a distance close to the personal space, 5 feet, a distance in the social space,

Figure 6: SARAH Set Up for a Twenty Foot Approach

10 feet, a distance in the public space, 20 feet, and a distance beyond any defined region, 40 feet. We chose to not approach from any closer that 5 feet because of the fact that we are approaching people entering a building. Any closer could potentially create a danger to people who are unsuspectingly entering the building in a rush. We performed 30 approaches from each distance, resulting in 120 total approaches.

4.3 The Interaction

While approaching, SARAH displays the face and speech bubble shown in Figure 7. The text reads: ”Can you help me with a simple task? Press 5 to accept.” Press 5 to accept, refers to 5 on the USB number pad attached to the front of SARAH, shown in Figure 5. This number pad allows people to interact with SARAH during the experiment. We then ask if the person can help with a simple task, because we are trying to represent something similar to the example described earlier with a robot needing help with an elevator.

If the person we approach choses to accept, they would press 5 on the number pad and the screen and text shown in Figure 8 would appear. The text reads: ”Does the following image contain a robot in it? Press 1 for no. Press 3 for yes.” The simple task we are asking for help with, is a simple yes-no question. This screen will be displayed for 5 seconds.

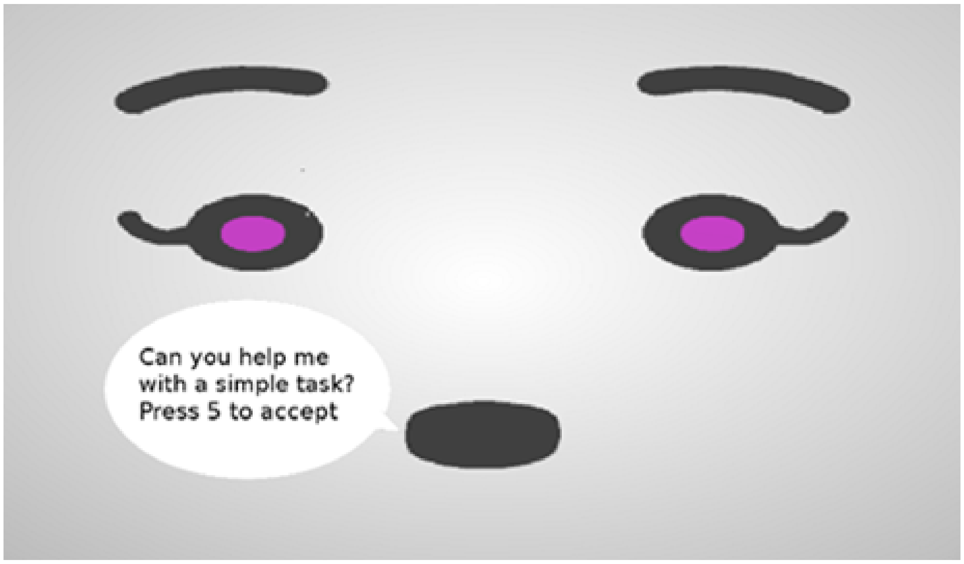

Figure 7: Face Seen While Approaching

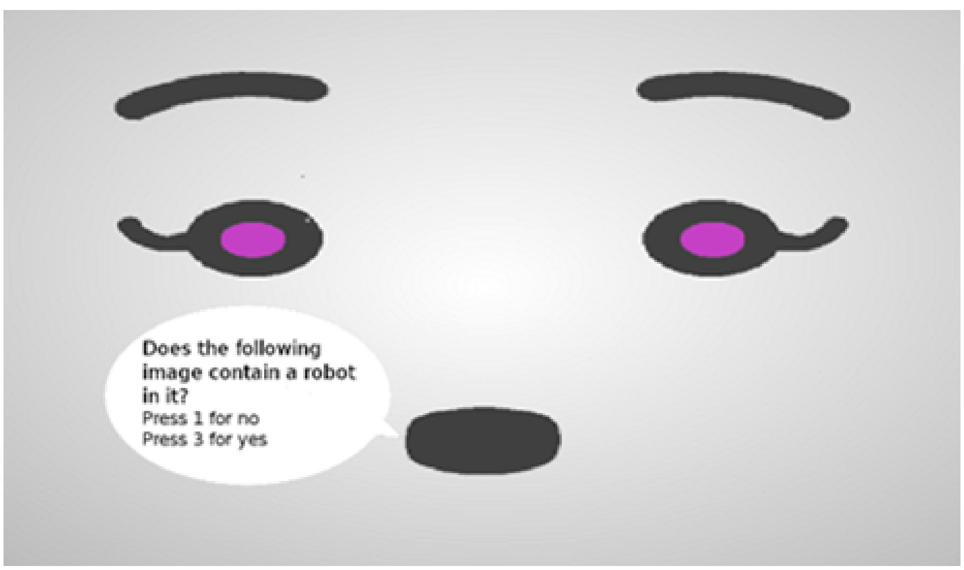

Figure 8: Face Seen After Initial Interaction

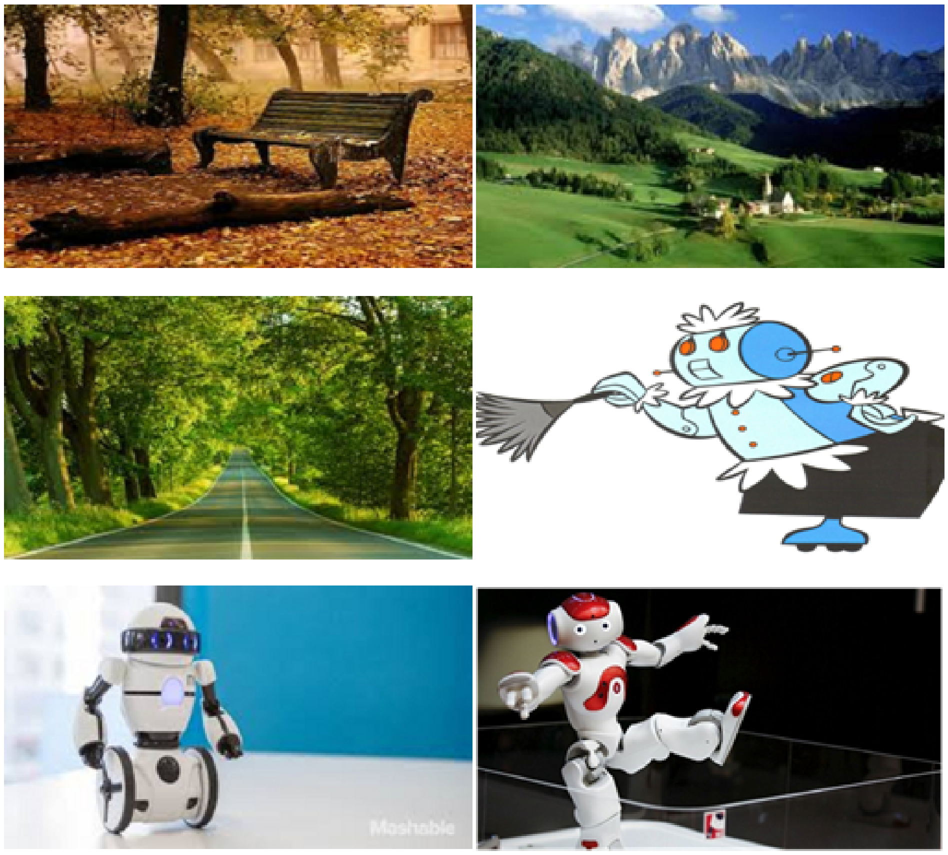

Figure 9: Random Images

Figure 9 shows all of the possible random images that could be displayed. The three of the random images are scenic views. The other three images have robots in them. Depending on which image is displayed, the approached person would press either 1 or 3. It does not matter if the person pressed the correct option, at this point we are not interested in command giving interactions between human and robot, only the willingness to interact.

Once the person we approach presses either 1 or 3, SARAH then displays the face and text seen in Figure 10. The text reads: "Thank you!" This is our way of telling the person we approached that we have finished with interaction.

What we consider a successful approach is if the person answers the question-answer task. By answer-

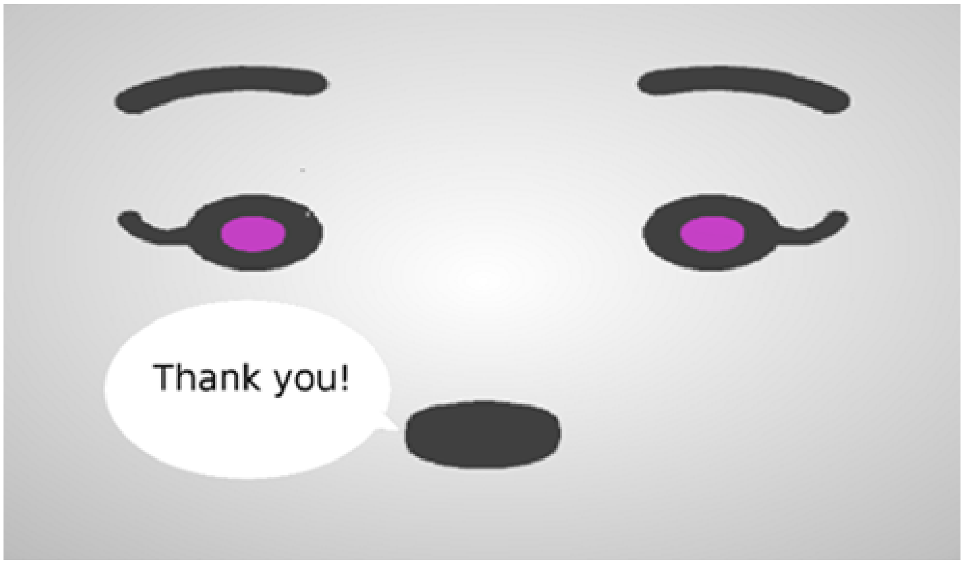

Figure 10: Face Seen After Helping Task

ing, the person shows their willingness to interact and help SARAH. Thus, our approach to get help was a success.

The interaction is controlled by a Python program that makes use of Pygame to handle the displaying of images and the number pad input. The interaction is done completely autonomously, the wizard has no control over the interaction. When Figure 8 appears, after the initial interaction, the wizard is alerted that an interaction has begun by having text output to their console. Once the interaction has finished, the wizard is also alerted that a successful interaction has occurred. At the end of the experiment the total amount of successful interactions is also printed to the console.

4.4 Measures

When analyzing each approach, it will be placed into one of three different categories: no attention, attention but no success, interaction with success. An approach that would fall into the first category, no attention, would be if the person just walks right by SARAH without slowing their pace or making any attempt to interact with her. We also consider a person going into a separate hallway or room before SARAH could reach them as an example of no attention. An approach that would fall into the second category, attention but no success, would be if the person stops and stares at SARAH but does not attempt to interact with her. Another example would be if they try to wave at her or talk to her, but again do not complete a successful interaction. As described in Section 4.3, a successful interaction would be helping with the question-answer task.

We were able to perform analysis on each approach by making use of a camera attached to the front of SARAH. The camera is not shown in Figure 5 however it was placed on the top of the cross beam that the number pad is attached to. We made use of a Flip UltraHD Video Camera.

5 Results

Again, the question we are trying to answer is, what is the most successful distance to start approaching someone for help? Before discussing the quantitative data found, it is important to note the qualitative data recorded by the wizard during the experiments. There was a wide variety of reactions to seeing the robot in the wild. Some showed extreme interest in SARAH, others were terrified by her. This was surprising to us because we have a lot of experience with SARAH and robotics in general. However, since this experiment was being performed in the wild with no control over the participants, we assume that there were a range of people with a range of experience in robotics. With that being said, after all of the approaches were run the analysis of the video footage showed that distance does play a role in whether or not the person we approached would help.

Figure 11 shows the affect distance has on successful approaches. Five and ten feet resulted in the most amount of successful interactions, five each. Twenty feet resulted in four interactions, and forty feet resulted in the minimum amount of successful interactions, three. Again, thirty approaches were attempted for each distance. Although there is a small difference between the minimum and maximum amount of successful interactions, there is a downward trend as the robot gets further away. To relate this back to Hall's work, we found that approaching from somewhere in the social space would result in the most interactions.

Figure 12 looks closer into the each approach, grouping each based on the three categories described in Section 4. Unfortunately, we there were technical difficulties that resulted in the loss of video footage for

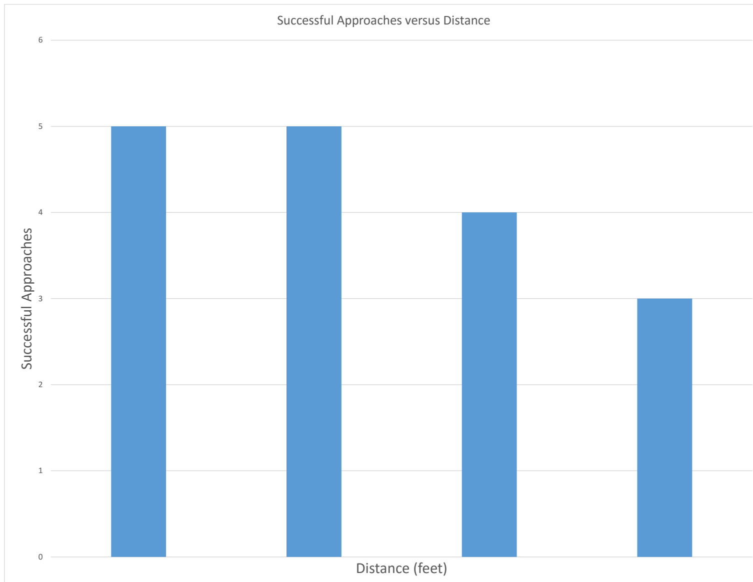

Figure 11: Number of Successful Approaches versus Distance

twenty feet. However, Figure 12 shows that approaching from ten feet resulted in the most amount of attention towards SARAH. When combining both attention and interaction, we see that fifteen, or fifty percent, of the approaches from ten feet resulted in the person being approached showing interest. Additionally, forty feet proved to result in the least amount of attention garnered towards SARAH as twenty-one of thirty approaches had the person give no attention to SARAH. An interesting thing to note about the forty feet approaches is that six of the twenty-one no attention approaches, were because the people entering went into the mail room before SARAH was able to get into ideal interaction position. On the other hand, no other distance had any approach end because someone was able to enter the mail room before passing SARAH. This relates back to our hypothesis that approaching from a far distance may not be ideal because the robot may not be able to reach the person before they leave the environment.

Figure 13 also shows that ten feet seems to be the most interesting distance that we chose to approach from. This figure shows the amount of fearful reactions to the robot approaching. What we considered a fearful reaction to be is when the person expressed some type of outwards reaction to seeing the robot approach. No fearful reaction resulted in a successful approach. An example of a fearful reaction is the

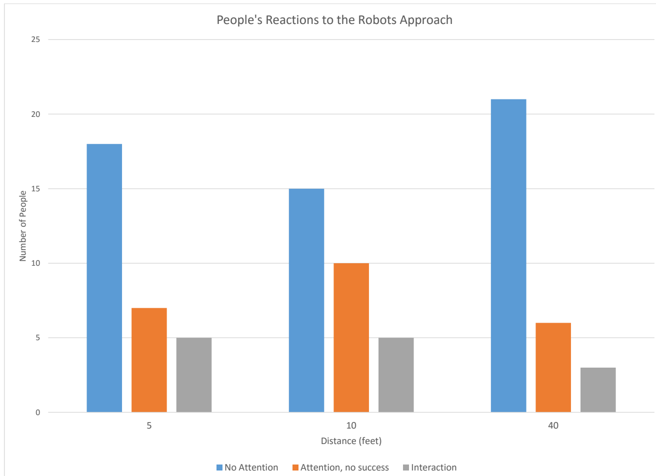

Figure 12: Varying levels of Interaction versus Distance

one fearful approach from twenty feet was when a female student entered, saw the robot approaching, and sprinted away from it and into the mail room. Another example is during a ten foot approach a female entered, took a few steps into the building, saw SARAH approaching, said ”oh my gosh”, took a step back, and then said ”nooo.” The fact that the maximum amount of fearful reactions, five, were from ten feet, further lead us to believe that ten feet is the most interesting distance. This is because it resulted in the most amount of extreme reactions, whether that be fully helping SARAH or being fearful. We look at people having an these types of reactions as a good thing because SARAH is definitely getting their attention. This is important because you need to notice SARAH before you interact with her, and these extreme reactions show she clearly got their attention. However, it is difficult to determine what a fearful reaction truly means because of the limitations of the in the wild experiment, in that we have no control over the participants.

Figure 14 show that seven out of the eight fearful reactions were from women. We found this to be extremely interesting and it may suggest something about how women perceive SARAH versus men. A potential reason for this may be that women are generally shorter than men, and as a result could be more threatened by SARAH who is closer to their height versus men. Unfortunately, from the video footage we

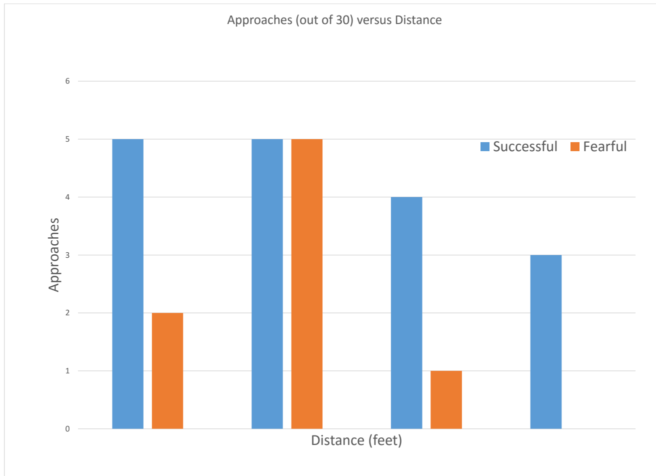

Figure 13: Number of Fearful Reactions versus Distance

have, we cannot determine the height of the participants. The role gender and height potentially play will be discussed further in Section 6.

Another interesting variable to look into, that also highlights ten feet, is group interactions versus individual interactions, as seen in Figure 15. When approaching, SARAH would only target an individual. However, that person may be entering with a group of people. Figure 15 shows that when approaching from ten feet, all of the successful approaches were when people were in groups. What this means, again, is difficult to say but it is a very interesting figure. Potentially, people feel more comfortable interacting with SARAH in groups, because they are unfamiliar with robots. However, we do not feel as though this skews the data showing ten feet results in the maximum amount of attention because we were not controlling for groups and we feel as though we did enough approaches from each distance that group size could have positively affected any of the distances. This will also be discussed further in Section 5.1.

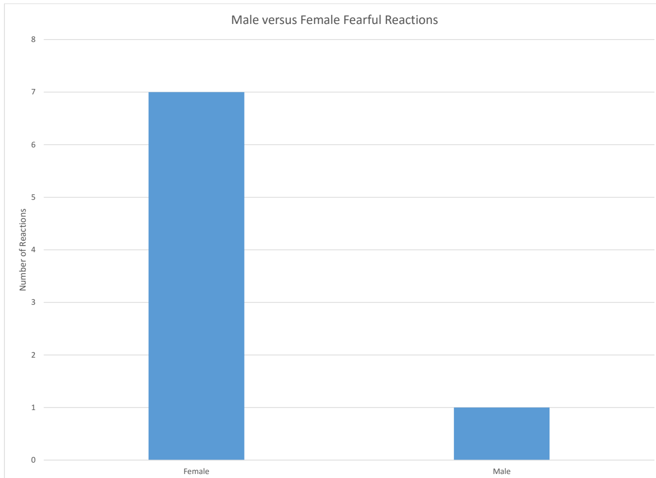

Figure 14: Number of Fearful Reactions Based on Gender

5.1 Threats to Validity

When discussing threats to validity we have to look into the trade-offs between internal, external, and measurement validity. Since we chose to do our experiment in the wild, we believe our results are generalizable. The building has very high traffic and is open to the public. As a result, we approached a wide variety of different people. Thus, we are confident we have high external validity. We feel very confident that if we were to do a similar experiment in other public spaces, similar results will occur. However, as discussed in Section 5, we have a lot of confounding variables. For example, gender and group size seem to play some role in the participants willingness to interact with the robot. This is a result of not doing the experiment in a controlled setting. Therefore, in order to achieve high external validity, we have low internal validity. Section 6 discusses experiments we hope to run to look into these confounding variables. Additionally, in terms of measurement validity, we are confident that the proxy we are using for the initial approach distance, distance from robot to entrance, measures what we want it to. We know that the distance from the person to the robot is the same as the distance from the entrance to the robot when the person is entering. And since we start our approach when the person enters, we know we are measuring the initial approach

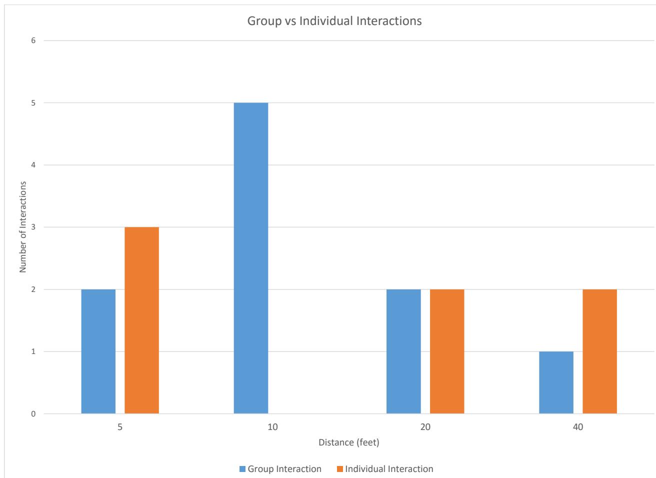

Figure 15: Amount of Successful Interactions for Groups and Individuals

distance correctly.

6 Conclusion and Future Works

In conclusion, we found that distance does play a role in who we should approach for help. We found that distances in the social range resulted in the most successful interactions. We also found as the initial approach distance increased, the amount of successful interactions decreased. Thus, we are now able to narrow down the pool of potential candidates. These potential candidates are the people who we could approach if we have a robot who needs help. We can now say that the robot will be more successful if it approaches someone who is roughly ten feet away rather than further away, forty feet. This experiment is just one step towards closing in on who the perfect candidate is to approach. It helps us have a better idea, and creates other interesting variables to look into.

As discussed in Section 5, group size, gender, and location seem to also play a role in successful interactions. From here, we would like to look into and devise experiments that have the following as the independent variable: group size, gender, location, speed of robot, sound during the approach, and an interactive face. These variables will be more steps into closing in on the perfect candidate. Group size could play a role because if you are unfamiliar with robots, maybe you would be more likely to interact in the comfort of a group. Gender seemed to play a major role in fearful reactions, which leads us to believe that potentially we should approach women differently than we should approach men. Or, maybe it has to do with height rather than gender, assuming of course the women we approached were shorter than the men. This could have to do with the height of the robot and the comfort level people have with robots that are a similar height as them. The location we ran the tests seemed to have some affect on the experiment as some people were able to go to the mail room before getting close to SARAH. Running the experiments in a closed hallway could be a potential future study to look further into this variable. Perhaps if SARAH were moving faster or slower people would be more or less likely to interact with her. If she were moving faster it could cause more fear, or it could cause people to realize she was targeting them, which could result in more interactions. Adding sound and an interactive face would make SARAH be more human like, which also could have a role on the level on interaction. Again, all of these variables will help us determine who the right person is to approach. Once, we have a better idea as to who to approach for help, we could then develop an algorithm that could be used on autonomous robots. This algorithm would take in data on all of these different variables, including distance, and determine who would lead to the most likely successful interaction.

7 Acknowledgments

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8 Appendix A: ROS

ROS is system that allows for different parts of the robot to interact through nodes. Nodes pass messages to other nodes through the use of topics which are continuous streams of data. A node can both subscribe and publish specific topics. Since SARAH is teleoperated, the controller that operates her publishes a joy topic with information about which buttons are being clicked and the direction of the joy stick. The p2os node is subscribed to the joy topic and when it recieves joy information, it converts it into a cmd-vel, command velocity, topic. The p2os node then publishes that cmd-vel topic which the RosAria node subscribes to. The RosAria node interacts directly with the Pioneer base and based on the cmd-vel topic information will move the Pioneer. RosAria translates the cmd-vel topics to ARIA commands, which is what the Pioneer understands. ROS makes it possible for us to remotely operate SARAH when performing our experiment to determine the most successful approach distance.

9 Appendix B: Wizard-of-Oz

A Wizard-of-Oz, WoZ, experiment is where the researchers are trying to make something appear autonomous to the participants. In our experiment, we have a ”wizard” controlling SARAH from a hidden location. This makes it so SARAH appears autonomous but in reality the ”wizard” has control. Riek [8] has created guidelines for WoZ studies which address the tensions in doing this type of experiment. A guideline we made particular use of is having specific instructions for the wizard to follow so that each approach can be as consistent as possible. The way the ”wizard” controlled the robot is discussed in Section 4.2.